n No. 361

NOTES ON INSPECTION

OF

STEEL FORGINGS

NAVY DEPARTMENT
BUREAU OF ENGINEERING

WASHINGTON
GOVERNMENT PRINTING OFFICE
1920

N. S. E. Form No. 361

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INTRODUCTION.

The following notes on the inspection of steel forgings have been compiled from methods in use in various inspection offices, and while they are not intended to prescribe a procedure to be followed in the inspection of this material they may be found useful to assistant inspectors not having had long experience.

INSPECTION OF STEEL FORGINGS.

1. CONTRACT AND SPECIFICATIONS.

The assistant inspector should thoroughly familiarize himself with the requirements of the contract or order and the Navy Department specifications in accordance with which the material is to conform. Any apparent inconsistency or condition in the contract or order which is not entirely clear should be brought to the attention of the Inspector in charge of the district, and instructions obtained before the inspection is begun.

2. MANUFACTURE OF INGOTS.

The use of acid or basic open-hearth furnaces and electric furnaces is approved. When the furnace charge, consisting of pig-iron, steel scrap and a suitable flux, has been reduced to the proper carbon contents, determined by means of ladle tests taken at varying intervals, it is tapped and the molten steel drawn off in a ladle or ladles, from which it is poured, usually from the bottom, into ingot molds. The ingot molds are generally so formed as to produce ingots of cylindrical form with fluted sides, or of square cross section. In each case the molds are tapered to insure ready withdrawal. In some cases the metal is poured into the top of the molds, called "top poured;" in others, through runners into the bottom of the molds, whence it rises to the top, called "bottom poured;" and less frequently into molds so arranged that the metal is subjected to hydraulic pressure while in the partial liquid state, called fluid compressed. After solidifying, the ingots are removed from the molds. If practicable, heat may be saved by transferring the hot ingot to the forge furnace, and after soaking it may be forged.

3. INSPECTION OF INGOTS.

Provided ingots are not charged (hot) direct from the molds into the forging furnace they may be inspected for defects and the data obtained recorded. The most common defects to occur in ingots are cooling cracks and defects in the surfaces caused by the splashing of the molten metal. The removal of these defects by chipping is permitted and the extent to which chipping may be done is usually covered by the specifications. In all cases the following data should be recorded:

(*a*) Name of the manufacturer.
(*b*) Heat number and serial number of ingot.
(*c*) Form of mold used, square, fluted sides, number of sides, etc.
(*d*) Dimensions and weight (in order to determine the discard).
(*e*) Kind of furnace used (acid or basic) (open-hearth or electric).
(*f*) How poured (top, bottom, or fluid compressed).
(*g*) Approximate weight of ingot mold employed.

If the firm manufactures its own ingots, the inspector should become acquainted with the process employed.

The use of sand-cast ingots is prohibited. Ingots so cast are inferior to chilled cast ingots, since forgings made from them are liable to contain ghost lines, areas of segregated nonmetallic inclusions and other defects. See paragraph 15 for further comment in this regard.

4. PROCESS OF MANUFACTURE OF FORGINGS.

Forgings are made both by hammer and hydraulic press, the larger ones by the latter method, since in addition to the better facility for producing the forging, a more thorough working of the metal is obtained. The ingots, especially nickel steel, should be carefully warmed before charging into a hot furnace. They are usually charged horizontally and with the top of the ingot protruding from the furnace door, all space not occupied by the ingot in the doorway being bricked up. If practicable the ingot should be charged into the furnace, permitting not over 20 per cent to remain cool. A chuck is attached to this cool top of the ingot by means of which the ingot is carried to the press or hammer and turned while in the process of being forged. In case of small forgings tongs may be employed. The ingot should be heated to about 2,200° F. and soaked at that temperature a sufficient time so that when forged the hot end does not become extremely concave or convex. Concave ends may be formed by not permitting sufficient soaking, thus the center being colder and consequently harder than the surface. Convex ends may be formed by permitting the surface of the ingot, which has been properly heated, to chill before forging is begun or to cool during forging.

In the forging of large shafts, etc., it may be necessary to reheat the partly forged ingot several times before forging can be completed.

When forged to a predetermined size the required amount of bottom discard is calculated, measured, and cut off.

The amount of top discard including the tong-hold should be calculated or weighed in order to determine that the required amount has been removed. Navy Department specifications prescribe a minimum reduction of area of the ingot and forging. This required reduction of area is usually 4 to 1 excepting for palms and flanges.

5. MARKING FORGINGS FOR IDENTIFICATION.

As soon as forged each forging should be stamped with a forging number supplied by the manufacturer, which should be a key to the ingot number, and this record kept by the inspector. The inspector should stamp the end of the forging "USN" and "M" (muzzle or top) or "B" (breech or bottom) to indicate the relative position in the ingot. These marks should be placed near the forging number.

6. HEAT TREATMENT.

The heat-treating equipment should be of an approved design and such as to evenly heat and cool the forging. The pyrometers should be so installed as to enable the inspector to satisfy himself that the forging is being uniformly treated. Uniformity of temperature may be noted by the color, and if the forging is not of a uniform color before quenching, it should be returned to the furnace and reheated.

7. TEST SPECIMENS.

Upon the submission of the forging after heat treatment, test specimens should be located in accordance with the specifications of the contract or order. B and M test bars are taken from prolongations provided on each end of forgings. The diameter of these prolongations should be at least equal to the greatest rough diameter of the forging except palms and flanges. In crank shafts, the section withstanding the greatest stresses is represented by the W and X bars and care should be exercised to guard against the drilling of holes or otherwise treating the shaft in order to produce a special heat treatment of the metal from which these test bars are to be taken. In all cases each specimen should be stamped with the forging number, USN, and letters indicating the location from where taken, that is, MI, MO, BI, etc. Specimens for metallographic examination need not be located until after the physical tests have been made. The removing of test pieces may be accomplished by trephining, slotting, or otherwise machining. Burning off of test pieces should not be permitted.

8. TESTING.

The assistant inspector should identify each test specimen after machining, and check up the dimensions to determine that they have been machined uniformly to the required diameter, and that the punch marks are exactly 2 inches apart. The surfaces of all tension test specimens should be free from tool marks and scratches. The excuse that poorly prepared test specimens are to the advantage of the Government should not be accepted, since accurate determination of the condition of the steel in the forging is desired as well as the information as to whether the steel is in full conformity with the requirements of the specifications. In case the inspector does not actually operate the testing machine, he should witness the operation and satisfy himself that the machine is being operated in a proper manner and that correct readings are obtained.

After breaking, each tension test piece should be examined for flaws appearing along its walls, as well as the grain structure as indicated by the fracture, and the assistant inspector should make note of the results of this examination.

The measurements for elongation and reduction of area should be taken by the assistant inspector.

The bending test may be made under a hammer, press, or by means of the testing machine. Specimens for bending tests should in all cases be approximately of the cross section required by the specifications. Bend specimens under ½ inch thick should be rejected.

Drillings for chemical analysis should be taken from that end of the forging representing the top of the ingot and are usually obtained from the bend test specimen, but may be taken from one of the "M" tension bars.

9. METALLOGRAPHIC SPECIMENS.

In case metallographic specimens are required the broken test specimens bearing the stamps necessary for identification and the additional specimens required should be properly marked and forwarded to the Engineering Experiment Station at Annapolis. These specimens should be accompanied by form N. S. E. 76, with entries to show the results of the chemical analysis and physical tests.

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10. INSPECTION DURING MACHINING.

Inspection during machining should be made to detect seams, ghost lines, etc. These defects may often be detected by the breaking of the chip, and such inspection will also prevent chipping and peening or the welding of flaws. As the machining of the forging proceeds it often becomes necessary to transfer stamps. In all cases the stamps should be transferred to the machined surface before the original stamp is machined off. The transfer of identification stamps should be made by or in the presence of the assistant inspector.

11. FINISH INSPECTION OF CRANK SHAFTS.

(*a*) A method which has been found satisfactory in the inspection of submarine crank shafts is as follows: Support the shaft on V-blocks of equal height placed under the main bearings Nos. 2 and 7, the blocks resting upon the surface plate. Measurements should be made with a surface gauge to insure that the shaft lies parallel with the surface plate and that there is no tendency to sag. Steps should be taken to insure that this alignment is maintained during subsequent inspection. The surface of the shaft should then be carefully examined for all defects such as deep scratches, small cracks, undercut fillets, etc., and the location of the oil holes should be checked. The diameter of each crank pin and each bearing should be measured by micrometer at points at right angles to each other for variation in diameter, and for deviation from exact roundness. The maximum variation in diameter rarely exceeds 0.002 inch.

(*b*) **Linear dimensions.**—With a machinists' scale the length of each crank-pin bearing and main bearing and the width and thickness of the webs and thickness and diameter of the flanges should be measured.

(*c*) **Inspection of throws.**—The location and dimensions of the key-ways should then be checked. As the bolt holes in the afterflange are drilled to a template furnished the manufacturer by the contractor and are reamed to suit the reversing mechanism after assembly, these holes need be checked only as to location with respect to the crank pins. The surfaces of the holes should be examined for possible defects in the flange. The accuracy of the angles should be checked by means of a dial gauge graduated to .001 inch. The shaft should be revolved until the parallel web surfaces of crank pin B, sketch A, are exactly at right angles to the surface plate. This alignment should be made with a machinist's square. The dial should then be adjusted so that a reading taken when moving the gauge over crank pin A gives a reading of about .050 inch. Readings should then be taken on crank pins 5, 3, and 4. These readings will probably be about as follows: .042 inch, .056 inch, .061 inch. The shaft should then be revolved until parallel surfaces of crank webs C are exactly at right angles to the surface plate, and without changing the gauge adjustment, reading should be taken on crank pins 1, 6, 2, and 5. These readings will probably be about as follows: .048 inch, .034 inch, .060 inch, .053 inch. The maximum error in angles is the difference between the least reading and the greatest, which in the above case is .061−.034 inch, which equals .027 inch.

(*d*) The above method should not be employed until after the web surfaces have been tested for parallelism with the planes passing through their respective pins and the journals. This may be accomplished by

placing each pair of pins in a position parallel with the surface plate and by means of the surface gauge determining that the web surface is parallel also.

(*e*) If it is not practicable to determine that the web surfaces are parallel, or if for any other reason it is desired, the following method may be employed:

The shaft should be revolved until the parallel web surfaces of crank pin B, sketch A, are approximately at right angles to the surface plate. A machinist's square may be used to obtain this alignment. The dial should then be adjusted so that a reading taken when moving the gauge over crank pin A, which is No. 2, gives a reading of about 0.050 inch. The machinist's square should then be removed and the shaft revolved sufficiently to cause the top of pin 2, and 3 corresponding to C, to lie in the plane parallel with the surface plate. Readings of the gauge for pins 2 and 3 are taken, and for illustration assume these to be 0.056 inch and the readings for pins 5 and 4 to be 0.042 inch and 0.061 inch, respectively. The shaft should then be revolved approximately 120°, and until pin 2 in its new position and with the adjustment of the gauge unchanged gives a reading of 0.056 inch. Assume the reading of pins 1, 6, and 5 to be 0.048 inch and 0.070, respectively. In like manner pin 3 should be revolved to the position indicated by A in the sketch, and in such a position that the gauge, still at its original adjustment, registers 0.056 inch. The readings of pins 1 and 6 should then be made. These may be assumed to be 0.053 inch and 0.048 inch, respectively. The maximum error in angles is the difference between the least and the greatest readings, which in the above case would be 0.070–0.042 inch, which equals 0.028 inch.

(*f*) **Calculations.**—The maximum error in angles is generally given in degrees and is usually about 0.5°. In order to determine this value in gauge readings in inches the following formula may be employed, assuming:

R = Radius of throw, inches = 7.0.
D = Angle of pins, degrees = 120.0.
D' = Maximum angle of pins, degrees = 120.5.
$X = (\text{cosine } D' - \text{cosine } D) \times R$.

In the above case the following results are obtained:

Cosine D' = cosine 120°.5 = sine 30°.5 = .50754.
Cosine D = cosine 120°.0 = sine 30°.0 = .50000.
R = 7.0 inch.
$X = .00754 \times 7.0 = .05278$ inch or approximately .053 inch.

When the difference between the least and the greatest gauge reading is less than .053 inch the error is less than 0.5°. The readings taken before revolving the shaft show that angles "D" and "E" are equal but do not show that they are 120°. Measuring angle "F" together with "D" or "E" proves that all the angles are approximately 120°.

(*g*) **Length of stroke.**—The throw of the crank should be measured by a height gauge, the web being at right angles to the surface plate. The error in stroke should be measured by revolving the shaft until the parallel web surfaces of each of the pins A, B, and C are successively at right angles to the surface plate, and then reading the gauge as shown in sketch B. All readings should be taken with the same setting of the gauge. The readings obtained will probably vary about as follows: .068, .059, .071, .078, .063, and .082 inch. The maximum error in stroke

is the difference between the least and greatest reading, which in this case would be

.082 inch $-$ .059 inch $=$ .023 inch.

The maximum error permitted in stroke is usually .030 inch.

(*h*) **Variation of axes.**—The variation of axis of any one main bearing from the axis of shaft when measured by revolving shaft on V-blocks may be obtained by adjusting the dial gauge to the bearing under test, revolving the shaft in the V-blocks and noting the deflection of the gauge.

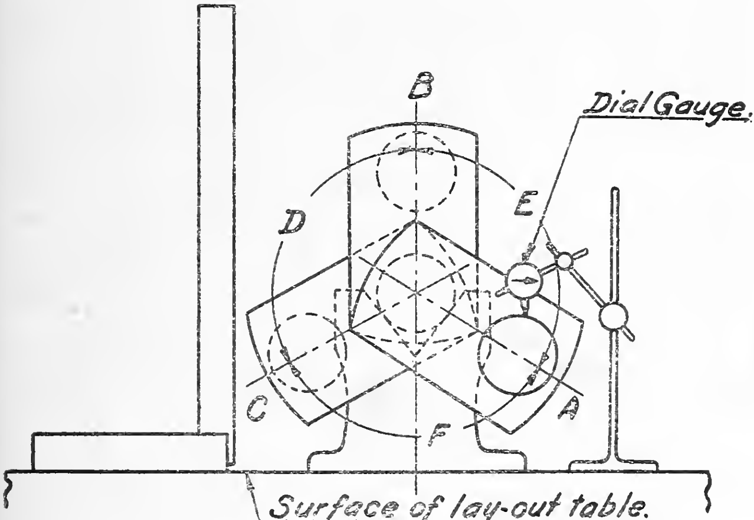
(*i*) **Inspection of coupling bolts, flanges, etc.**—Submarine crank shafts usually consist of two sections. After the above tests have been made these sections are disconnected. The fit of the coupling bolts, which is a driving fit, is indicated by the effort required to remove the bolts. After the section has been disconnected the surfaces of the coupling flanges should be examined to discover evidences of piping, ghost lines, etc.

12. FINISH INSPECTION OF HOLLOW-BORED SHAFTING.

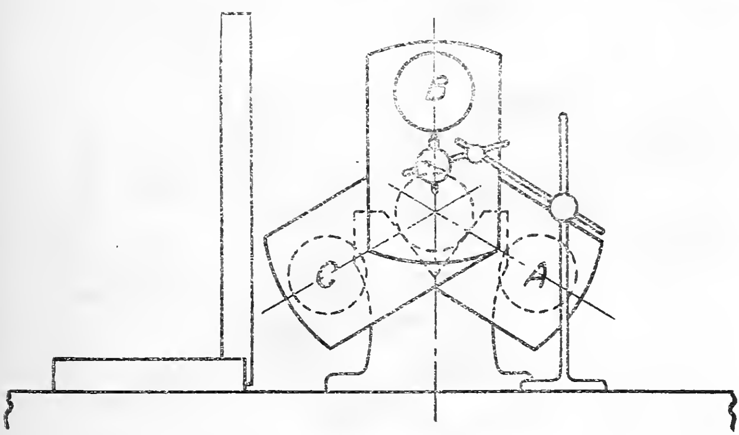
(*a*) In order to provide the required strength with a minimum of weight, shafts are usually bored as follows: Line shafts are bored the same diameter throughout; stern-tube shafts are bored with the large hole extending nearly to the after end; and propeller shafts are bored with a large bore from the end upon which a collar about $1\frac{1}{2}$ times the diameter of the shaft has been left nearly to taper for propeller. To bore the small holes the last two shafts are turned end for end and the small holes are then bored to meet the large hole. The small hole should be first bored smaller than finished dimensions, say 2 inch diameter for a 3-inch hole, then measurements taken and shaft centered by the large hole so that when the small hole is then bored it will be concentric with the large hole. Propeller shafts generally have small holes at each end. After boring the large hole and the small hole in one end, the end of the shaft bearing the collar is heated and the collar reduced by forging until the hole is nearly closed. The small hole is then bored in a manner similar to the boring of the small hole in the opposite end of the same shaft. This closing in of the shaft ends should in all cases precede final heat treatment and tests.

(*b*) **Inspection of surface.**—Upon the submission of the shafts, finish machined or rough machined as required by the order or contract, such shafts should be surface inspected for flaws, seams, black spots, ghost lines, etc. The diameters of rough machined shafts may be measured by means of calipers. Diameter of finish machined shafts should be determined by means of micrometers. Lengths should be checked by the use of a steel tape.

(*c*) **Inspection of bore.**—The bore should be carefully inspected for uniformity, concentricity, and flaws, such as piping, etc., and that the proper boring cutter has been used to cut the proper angles between the large and small bores. The bores of propeller shafts should be inspected before closing in. After successfully passing the above inspection the hollow-bored shafts should be placed in a lathe or on suitably designed rolls, measurements taken at ends of the shaft to determine thickness of shaft walls, and the bore indicated by means of an apparatus similar to the sketches shown.



Sketch A.



Sketch B.

ption of sketch of electrical indicator.

The shaft the bore of which is to be inspected is placed in a lathe, chucked at one end and supported near the other end by a carefully adjusted steady rest, in such a manner as to cause the shaft to run true with the outside.

The indicating apparatus consists of a pipe 16 feet long and of sufficient outside diameter to prevent sagging and small enough to pass through the reduced bore of the shaft. One end of this pipe is clamped securely to a "slide rest" and on the other end is attached a finger or lever. This lever is so pivoted that it may be adjusted parallel with the pipe when passing through the reduced bore, and can be made to assume a transverse position, shown in the sketch, by means of a wire running through the pipe, the wire being held taut and secured so as to hold the lever firmly fixed.

The tip of the lever is insulated from the pipe and an insulated wire runs from this tip through the pipe to a switch of the lighting circuit. The other side of the circuit is grounded to the lathe bed as shown, both switches being closed when the apparatus is in use.

The pipe is marked off on the outside every 2 feet, longitudinally from the lever tip in its fixed position, so as to determine just where measurements are taken; and the intermediate points are determined by a rule laid along the pipe at the end of the shaft. With a 16–foot pipe, measurements can be made up to about 14 feet inside the shaft.

By means of the slide rest, the apparatus is moved to any desired position in the shaft, working first from one end and then the other end of the shaft, if it is more than 14 feet long. The transverse feed of slide rest provides for movement of the apparatus transversely, and as soon as lever tip touches wall of the shaft, the electric lights shown in the circuit flicker or light up. The travel of the lever tip should be in the horizontal plane of the axis of the shaft for accurate measurements; but for practical purposes the eye is accurate enough when adjusting the pipe in clamps of slide rest, with the free end of pipe just entered in the shaft. Two scales are laid on transverse bed of slide rest in order to measure the exact transverse movement of the apparatus.

Use of apparatus.

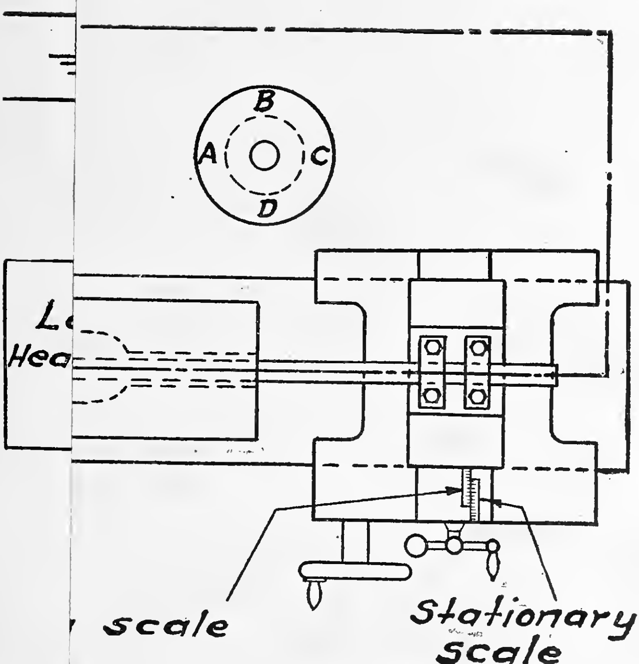
The different quadrants are indicated on the end of the shaft by the letters "A," "B," "C," and "D"; apparatus being secured in proper position in slide rest and moved into shaft to proper position for first measurements of bore. The lever is then hauled back and secured in position.

With shaft slowly revolving, using transverse feed of slide rest, contact point is moved until it touches the surface of the bore, when the lights in the circuit will flash, indicating that a "high spot" has been touched. The point on the circumference which has been touched is noted, and is indicated by a mark on the end of the shaft, and the scale reading on slide rest is taken. Then the shaft is turned so that the "high spot" detected is 180° from the contact point of the lever. With the shaft fixed in position, the apparatus is again fed transversely until the lights flash. The scale reading on the slide rest is again noted and the difference between the two readings shows the movement of contact point. One-half of this movement is the amount the axis of the bore is eccentric.

When more than a slight eccentricity is noted, careful measurements of the bore should be taken, each 2 or 3 inches in length, and in each quadrant. Ordinarily indications are made only every 2 feet of length.

Comment.

The above apparatus should only be used when the bore of the shaft has been carefully searched with an electric torch and it has been found that the bore



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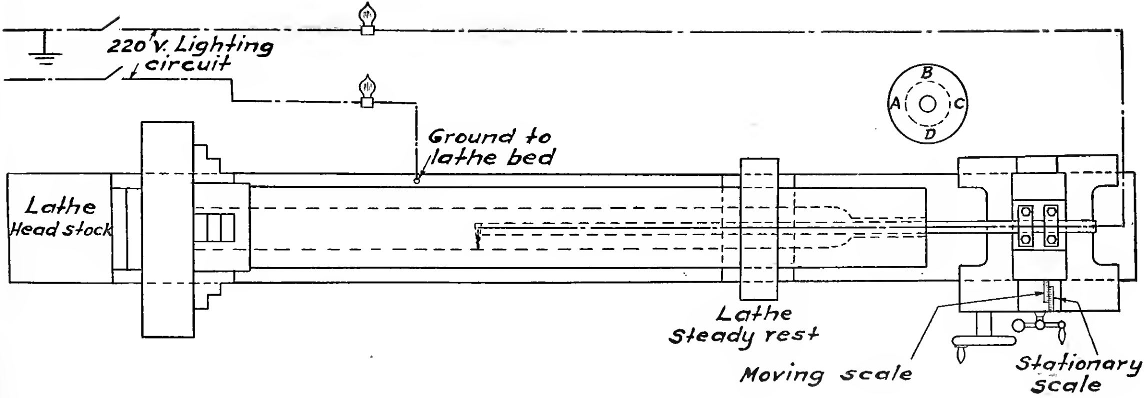

ELECTRICAL INDICATOR

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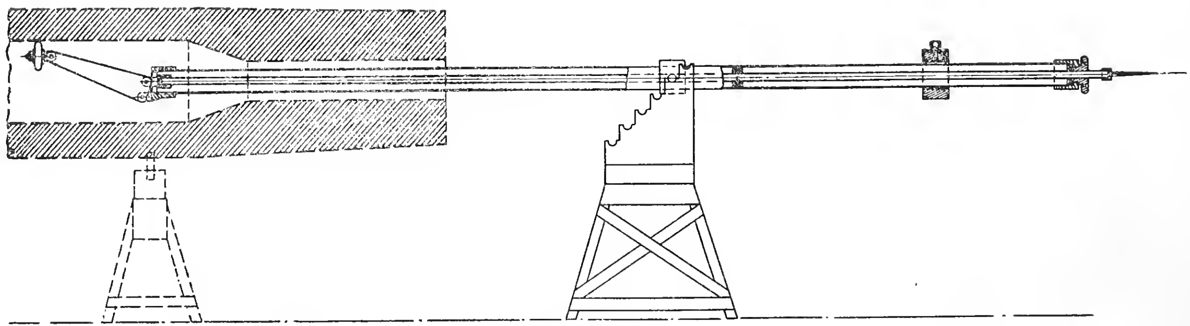

MECHANICAL INDICATOR

has no serious defects or irregular cutting on the part of the boring tool. Particularly with a shaft which has "closed-in" ends the bore should be carefully examined before the ends have been closed in, since it is very difficult to examine the bore through the small hole after the end is closed in, and in this case the above apparatus might not show up a local flaw, hump, or spiral groove in the bore.

When using the apparatus care must be taken not to start the 16-foot pipe vibrating, as the free end will easily vibrate over an inch, and take a minute or two to come back to rest. Also, moisture must be eliminated at the electric contact point for accurate readings.

The apparatus appears accurate for measurement of eccentricity of the bore at any desired point, provided the cross section at that point is a circle. If the cross section is elliptical or otherwise irregular, it will be necessary, in order to show up the true form of the bore, to take a large number of readings, which would require a great deal of time.

Mechanical indicator.

A sketch of a mechanical indicator which has been used is shown on the opposite page.

(*d*) **Tolerance in eccentricity.**—In the absence of other instructions an eccentricity of the axis of the large bore of rough machined shafts of $\frac{1}{32}$ inch and an eccentricity of the axis of the small or reduced bore of rough machined shafts of $\frac{1}{16}$ inch is generally permitted. A variation in wall thickness measured at points 180° apart of the circumference corresponds to twice the eccentricity of the axis of the bore. A variation in wall thickness of $\frac{1}{16}$ inch, measured 180° apart of a circumference, corresponds to $\frac{1}{32}$ inch eccentricity of the axis of the bore. The length of bores should conform to the requirements of the drawings, except for propeller shafts with closed-in end. After boring it is impossible to forge down the open end so that the taper and bore will exactly agree with the drawing. In no case should the large bore extend farther than specified, since the shaft is tapered for the coupling and the propeller, and the strength would thus be impaired. The maximum length of the large bore should be that shown on the drawing.

(*e*) **Tolerance of diameter of bore.**—The tolerance of diameter of bore is usually stated on the blue print. The provisions of the General Specifications for Machinery E3, May 1, 1919, in this regard are as follows: "The tolerances in diameter of bore will be $\frac{1}{8}$ inch under size and $\frac{1}{16}$ inch over size."

(*f*) **Straightening shafts.**—Any working below forging heat should be very carefully watched as initial stresses are liable to occur at the point where bending is done. Shafts that have been warped or bent slightly while undergoing heat treatment may be straightened by reheating to not over 700° F. In case such forgings are heated over 700° F. complete retests should be required.

13. FINAL INSPECTION.

(*a*) The assistant inspector must be assured by actual checking that all dimensions are in accordance with the requirements of the specifications of the contract or order, and permitted tolerances, and that in the case of rough-turned shafting there is sufficient metal for finish machining. Careful examination of all surfaces must be made for hair-line cracks, streaks, and ghost lines.

14. SMALL FORGINGS.

The inspection of small forgings should be conducted in the same manner as large forgings except that tests may be taken to represent a lot as defined by the specifications. Metal for test should be provided by the manufacturer on several forgings in each lot in order that the assistant inspector may select such forgings as he may desire from which to obtain test specimens. In lieu of providing extra metal for testing, the manufacturer may request the assistant inspector to select a forging for test.

15. GHOST LINES.

Ghost lines sometimes exist in forgings, and in all inspections of machined surfaces of forgings care should be exercised to detect such defects, and if they exist to report to the Inspector in order that a special investigation may be conducted to establish their extent.

Due to the different temperature of solidification, there is a tendency of certain nonmetallic constituents, such as sulfides, silicides, etc., to gather into areas in an ingot as the metal becomes solid. As the steel on cooling passes from the austenitic to the sorbitic and thence to the pearlitic stage, ferrite is freed and each particle of nonmetallic substance is surrounded by pure ferrite. If the nonmetallic particles are numerous and due to forging, the area has been elongated, a line or streak of metal of color unlike that surrounding it appears. This line has been given the name of ghost line.

As stated, the nonmetallic substances are surrounded by free ferrite, drawing such ferrite from the surrounding pearlite and ferrite, thus increasing the carbon content of the metal adjacent to the ghost line, with a resulting hardening of same. This increasing of the carbon content of the steel surrounding a ghost line and thus rendering it harder explains the jumping of the tool and the consequent ridge on the forging.

Forgings made from ingots cast in metal molds are less likely to develop ghost lines than those made from ingots cast in sand. The longer time the metal remains liquid in the ingot mold the greater the segregation of impurities with resulting ghost lines.

16. STAMPING AND WEIGHING.

After final inspection has been completed and it has been determined that the forging is in accordance with the requirements of the contract or order it should be stamped "USN" and U⚓S adjacent to the forging number. The forgings should also be stamped with identification numbers or letters if such are required by the order. Crank shafts should be stamped on the face of one of the webs. Care should be exercised that stamping of finished forgings is not done on bearing surfaces. In all cases forgings should be weighed by the assistant inspector and note that weight was checked made on the Report of Material Shipped.

CONCLUSION.

The foregoing is an outline of a procedure in the inspection of this class of material. In general, since the contractors furnish the means and the labor necessary to establish that their product is satisfactory, their methods of checking dimensions, alignments, etc., should be employed, provided there be no reason to doubt the accuracy of the results obtained thereby. The inspector has the right to recheck by his own methods, but should exercise this right only in case conditions obtain during inspection under the contractor's methods which render such action advisable.